Estimating the number of northern pike in Mille Lacs, Minnesota in 2013 and 2014.

Prepared for the Minnesota Department of Natural Resources

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1. Introduction

The Minnesota Department of Natural Resources conducted a mark-recapture experiment to estimate the number of northern pike in Mille Lacs, Minnesota in two separate surveys run in spring/summer of 2013 and in spring/summer 2014. The study protocol is fully described in Jones (2013).

Briefly, approximately 5500 in 2013 and 3700 in 2014 northern pike were captured on the spawning grounds in late April and early May (Tables 1a and 1b). In 2013, these fish were sexed, fin clipped (with the position of the fin clip dependent upon the sex), and released without tags. In 2014, the fish were sexed, fin clipped and also tagged before being released. In 2014, if a fish was already tagged (from a previous study), the old tag was retained, and the fish was considered to be newly tagged in 2014. Other variables (such as location of the spawning ground, length of the fish, etc.) were also recorded. Some fish were recovered by the Tribes after the spawning sessions but prior to the gillnet sample (below), but the number is not known. This does not cause a problem as long it is assumed that removals by the Tribes are at random from clipped and unclipped fish, i.e. the Tribes do not preferentially harvest tagged fish.

Sampling gillnets were set between late-May to late-June. Approximately 1000 in 2013 and 1200 in 2014 unclipped/untagged northern pike were captured, plus an additional 101 in 2013 and 90 in 2014 recaptures from the fish released on the spawning grounds as determined by the presence of the fin clip. The sex of the recaptured fish was known. In 2013, about 25% of the newly captured fish were not sexed, but virtually all newly captured fish in 2014 were sexed. Other variables (such as location of the gillnet, length of the fish, etc.) were also recorded.

The population of interest are northern pike greater than 18" in length at the time of tagging (spawning) including removals by the Tribes[1]. Because the time interval between the tagging/clipping and the gillnet sample is short, the population is assumed to be closed with negligible deaths or recruitment to the population. The usual assumptions for a closed population capture-recapture study are made, including

- Marks are not lost between sampling occasions. Because fish are fin-clipped and the time interval is short, clips are unlikely to be "lost" due to regrowth. Tags may be lost, but previous studies (Schwarz, 2006) on northern pike have found only a small tag loss rate over short periods (less than 2% in the first 270 days after tagging).
- Marked fish can be correctly identified. The examination of fish was done by MDNR members so this again seems reasonable. Fish in 2014 were also tagged with numbered tags to differentiate the fin-clipped fish from those in 2013 (no tags) and 2014.
- Mixing of tagged and untagged fish. Tagging/clipping was done at many spawning locations around the lake as was the gillnet survey. However, there was only a short period of time between the end of the marking and the start of the gillnet sampling. If tagged/clipped fish have not fully mixed with other fish from spawning grounds not sampled, there is the potential for substantial bias.

Several estimation methods will be applied to this experiment. All estimation was performed using R 3.1.1 (R Core Team 2013)

2. Pooled-Petersen Estimator

A breakdown of the number of fish clipped, recaptured, and newly recaptured is found in Table 2. The simple Petersen estimates, combined over both sexes are

2013 53 (SE 5) thousand fish
2014 52 (SE 5) thousand fish.

The simple Petersen estimate can be biased because of heterogeneity in catchability between the two sexes or over covariates (such as length) or a differential change in catchability between the two sampling occasions for the two sexes. Seber (1982) showed that the bias in a simple-Petersen estimate is related to the negative correlation of the catchability between the first and second sampling occasion.

3. Stratified-Petersen on the basis of sex alone

If sex was measured for all fish at both sampling occasions, then it is relatively simple to compute a stratified-Petersen estimate by finding the Petersen estimate for each sex separately, and then adding the two estimates together.

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[1] Because removals from the Tribes occurred after the spawning period and before the gillnet removals, they have no impact on the population estimates.

Nearly all fish were sexed in the tagging and recapture samples in both years. However, in 2013, about 25% of fish newly captured in the gillnets were not sexed. In 2014, nearly all fish were sexed in the gillnet sample.

We estimated abundance in two way. First estimates were obtained using the specialized program (partially-stratified Petersen) developed for the estimation of walleye abundance and second, by imputing sex based on the length of the northern pike.

The key assumption needed to use the partially-stratified Petersen method is that those fish actually sexed are a random sample of all fish captured. This will be key for the 2013 analysis where approximately 25% of the newly captured fish in the gillnet sample were not sexed. The summary statistics for this method are found in Table 2 and the estimates of abundance are

2013 54 (23 F; 30 M) thousand fish with estimated standard errors of
5 (3 F; 5 M).

2014 52 (24 F; 26 M) thousand fish with estimated standard errors of
5 (4 F; 4 M).

In the second method, the length of the fish was used to impute sex when sex was unknown for a fish. A logistic regression was fit to all northern pike data (including past years) where the probability of being a male was modeled as a function of length (Figure 1). This fitted model was used to classify an unsexed-fish as male/female using a binomial distribution depending on the predicted probability of being male. If the sex was known, the known sex was used.

If these imputed values are used directly in a fully stratified Petersen estimator (i.e. a separate estimate for each sex; summary statistics in Table 2), this gives estimates of

2013 54 (25 F, 29 M) thousand fish with standard errors[2] of
5 (3 F, 4 M)

2014 52 (25 F, 27 M) thousand fish with standard errors of
5 (4 F, 4 M)

Both sets of estimates are very similar to the pooled-Petersen values. While the capture probability was quite different for males and females on the spawning grounds (female probability about twice that of males in 2013 and 50% higher in 2014), the average capture probability for both sexes were almost identical in the gillnet sample. The latter is one of the conditions under which the pooled-Petersen estimator remains unbiased. Only in 2013 were substantial numbers of fish not sexed. In 2014 fewer fish were unsexed so the imputation process was only needed for a few fish. In both years, the estimates were again similar among the methods.

[2] These SE are slightly too optimistic because of the randomness in imputing sex has not been accounted for in 2013.

4. Stratification by sex and length - I

Catchability may also vary by length within each sex at both samples because of gear selectivity. Pure heterogeneity in catchability (e.g. gear selectivity with the same shape in both samples) implies that there is a positive correlation in catchability between the two samples which could lead to a negative bias in the estimates of population abundance.

Figures 2a and 2b shows that the distribution of lengths does differ between captured males and females in all the samples, but appears to have the same distribution across samples for each sex with captured females tending to be longer than males.

A stratification by length and (imputed) sex could be computed in a similar fashion to stratification simply by sex as seen earlier. Because of the relatively small number of recaptures, three length strata were defined 18-25", 25-30", and 30+". The summary statistics are shown in Tables 3a and 3b. Few male fish were captured in the upper stratum (30+") in the gillnets in either year.

Estimates of the abundance for males and females for each stratum and the overall total were obtained (Tables 4a and 4b). The overall population estimates are

2013 54 (25 F; 29 M) thousand fish with standard errors[3] of
6 (3 F; 5 M)

2014 62 (20 F; 41 M) thousand fish with standard errors of
9 (3 F; 8 M).

The sex-and-length stratified estimate in 2013 is similar to the unstratified estimates. The estimate for 2014 is substantially larger than the unstratified estimates, but with a much larger standard error (the confidence intervals all overall). This large estimate in 2014 appears to be caused by very few male fish being recaptured in the largest length class which causes an inflation in the population estimate with a corresponding inflated standard error.

5. Stratification by sex and length - II

The previous section required that the length be divided into a small number of strata. Chen and Lloyd (2000) developed a method where no stratification is needed – a smoothed estimate over all lengths is used to estimate a Petersen estimate based on a moving window.

Chen and Lloyd (2000) only considered stratification by a single covariate. In this problem we have the additional complexity that not all fish in the gillnet sample in 2013 were sexed. A similar procedure was used as in the walleye analysis where the imputed sex was used based on the length of the fish as described earlier. Summary statistics are presented in Tables 5a and 5b. Note that for small length classes for females and larger length classes for males, the number of fish in the length interval was too small to be

[3] These SE are slightly too optimistic because of the randomness in imputing sex has not been accounted for in 2013

useful and the distributions were truncated accordingly. This may lead to a slight underestimate of abundance by ignoring fish in these (missing) length classes.

The estimated abundance (by length) is shown in Figures 3a and 3b. The estimated total population abundance using the modified Chen and Lloyd method are

2013 48 (17 F; 31 M) thousand fish with estimated (corrected) SE of 8 (2 F; 8 M)

2014 56 (22 F; 34 M) thousand fish with estimated (corrected) SE of 8 (4 F; 6 M)

The estimated total abundances are slightly smaller than that from the stratified sex and length method with 3 length classes. The distribution of males appears to decline rapidly with length but the distribution of females is more constant over lengths in both years.

The estimated selectivity curves for the two sexes in the two samples are presented in Figures 4a and 4b. Selectivity was higher on the spawning ground than the gillnet surveys in both years. Selectivity also appears to be low for all fish in all sample less than 20" in length.

6. Movement and mixing

Another potential source of heterogeneity in catchability is the lack of mixing between the two sampling events because of geographic distance. Because fish in 2013 were not individually tagged, this analysis can only be done on the 2014 data. The tag number on the recaptured fish was used to link the recapture zone with the tagging zone in 2014. As shown in Figure 5, tagging/clipping and gillnet sampling occurred around the lake.

To investigate if the recapture probabilities differ depending on where tagged, the tagging and recapture zones were classified into two broad geographic strata – east or west based on UTM easting 450000. The summary data are presented in Table 6. A formal test for differential gross recapture rates failed to find evidence of a difference for both sexes, but the small number of recaptures likely implies that the power is low to detect anything but gross differences. The mean time at large for recaptured fish was also compared (Table 6). There was some evidence of a difference in the mean time at large depending on where initially tagged with fish tagged in the west being at large approximately 6 more days than fish tagged in the east. Tagging begins about a week earlier on the west side creeks and the Rum River outlet because these areas tend to open up sooner in the spring. The Rum River is a major source of pike. This may explain the extra days at large.

An investigation of the degree of potential bias due to geographical stratification being ignored is presented in Table 7. The tagging/clipping, recaptures, and gillnet recoveries were stratified into the two strata East or West as noted earlier. The data were also pooled over sex to avoid having to model the sex distribution of the sample in each geographic stratum as was done earlier. The pattern of recaptures in Table 7 shows that fish are recaptured about twice as often in their stratum of releases (diagonal elements of the

movement matrix) than in the other stratum and so mixing does not appear to be complete around the lake.

The key message from Table 7is to see the extent of possible bias introduced by ignoring the geographical stratification. In this case the difference between the stratified and unstratified estimates is negligible given the standard errors seen on the earlier estimates. Therefore at a gross level, there does not seem to be any reason to develop an estimator stratified by sex, length, and geographical stratum. This is likely due to the very small difference in catchability from releases in the different geographic strata (Table 6)

7. Discussion

Estimates from the various methods were all very similar in both years (Figure 8). The amount of bias introduced by pooling over the sexes is expected to be small because of the similar (average) catchability between the two sexes. There appears to be little evidence of a bias from geographic stratification again because of the approximate equal catchability between the two strata. The estimates of abundance using a length stratification are also comparable, but the large standard errors in the estimate make it difficult to detect anything but gross violations – Figures 4a and 4b indicate drop off in catchability for fish less than about 22" in length so estimates in all cases may be too small and not properly accounting for fish between 18" and 22".

The key unresolved issue with these models is the low selectivity for fish between 18" and 22" inches. Here the data are very sparse, and no good estimate of the abundance of this segment of the population is available. Auxiliary information such as harvest information by length class of tagged and untagged fish may provide some information about the relative sizes of these smaller age classes which can then be used to augment the results of the tagging study.

References.

Chen, S., Lloyd, C., 2000. A non-parametric approach to the analysis of two stage mark-recapture experiments. Biometrika 88, 649–663.

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Schwarz, C. J. (2006). Analysis of the mark-recapture studies for northern pike in Mille Lacs, Minnesota – 2006 report. Prepared for Minnesota Department of Natural Resources. 2006-12-06. 65 pp.

Seber, G. A. F. (1982). Estimation of Animal Abundance, 2nd Edition.

Table 1a. Summary statistics for the 2013 survey.				
	Female (adipose clip)	Male (dorsal clip)	Unknown (caudal clip)	Total
Gross Tagged/clipped 2013-04-19 -> 2013-05-17	3193	2098	6	5297
(fish less than 18")	-35	-114	-1	-150
Net Tagged/clipped	3158	1984	5	5147
Recaptured in gillnet 2013-05-23 -> 2013-06-21	68	40	3	111
Gross newly captured in gillnet	332	443	253	1028
(fish less than 18")	-0	-2	-1	-3
Net newly captured in gillnet	332	441	252	1025

Table 1b. Summary statistics for the 2014 survey.				
	Female (adipose clip)	Male (dorsal clip)	Unknown (caudal clip)	Total
Gross Tagged/clipped 2014-04-16 -> 2014-05-14	1871	1769	19	3659[4]
(fish less than 18")	-26	-70	-0	-96
Net Tagged/clipped	1845	1699	19	3563
Recaptured in gillnet 2014-05-20 -> 2014-06-13	40	47	6	93
Gross newly captured in gillnet (never tagged)	508	708	49	1265
(fish less than 18")	-1	-6	-1	-8
Net newly captured in gillnet	507	702	48	1257

[4] Includes 6 fish that are clipped, but did not have a tag applied.

Table 2. Summary statistics used for the Petersen estimators.

Summary statistics for Pooled-Petersen estimator	**2013**	**2014**
n_1 (marked)	5147	3567
m_2 (recaptured)	111	93
n_2 (sample 2)	1137	1351

Summary statistics for Partially-Stratified Petersen estimate assuming sexing was done at random		
History	Count	Count
U0	3	14
UU	2	5
0U	252	48
M0	1944	1652
MM	40	47
OM	441	702
F0	2090	1805
FF	68	40
0F	332	507

Summary statistics for Stratified-Petersen estimator with imputed values for number in each sex in gillnet sample.		
n_{1f} (marked)	3159	1854
n_{1m} (marked)	1988	1709
m_{2f} (recaptured)	69	43
m_{2m} (recaptured)	41	49
n_{2f} (sample2)	536	576
n_{2m} (sample2)	599	773

Table 3a. Summary statistics used for stratification by length and (imputed) sex in 2013[5]			
	Female	Male	Total
Tagged/clipped			
18-25 in	1010	1510	2520
25-30 in	814	418	1232
30+ in	1345	60	1405
Recaptured in gillnet			
18-25 in	14	31	45
25-30 in	27	31	58
30+ in	28	1	29
Newly captured in gillnet			
18-25 in	136	320	456
25-30 in	198	211	409
30+ in	133	27	160

Table 3b. Summary statistics used for stratification by length and sex in 2014[6]			
	Female	Male	Total
Tagged/clipped			
18-25 in	577	1322	1899
25-30 in	595	356	951
30+ in	682	31	713
Recaptured in gillnet			
18-25 in	7	26	33
25-30 in	24	19	43
30+ in	12	3	15
Newly captured in gillnet			
18-25 in	220	546	766
25-30 in	172	153	325
30+ in	143	23	166

[5] Numbers do not total to Table 1a because a small number of fish did not have length measurements taken.

[6] Numbers do not total to Table 1b because a small number of fish did not have length measurements taken.

Table 4a. Abundance Estimates from sex and length stratified model in 2013 (thousands)						
Stratum	M+F Est	M+F SE	F Est	F SE	M Est	M SE
18-25 in	28	4	11	3	16	3
25-30 in	17	3	7	1	10	3
30+ in	9	2	8	1	2	2
ALL	54	6	25	3	29	5

Table 4b. Abundance Estimates from sex and length stratified model in 2014 (thousands)						
Stratum	M+F Est	M+F SE	F Est	F SE	M Est	M SE
18-25 in	43	8	5	1	38	8
25-30 in	8	1	6	1	3	1
30+ in	10	3	10	3	.3	.1
ALL	62	9	20	3	41	8

Table 5a. Summary data for 2013 for modified Chen and Lloyd method.

	Males				Females			
Length Centre (inches	Tagged/ Clipped	Recap	Imputed Unclipped	Recap prob	Tagged/ Clipped	Recap	Imputed Unclipped	Recap prob
18.5	154	0	7	0.000				
19.5	163	0	9	0.000				
20.5	216	1	27	0.005				
21.5	234	4	35	0.017	151	0	12	0.000
22.5	267	5	78	0.019	178	3	14	0.017
23.5	263	10	68	0.038	172	7	24	0.041
24.5	213	11	86	0.052	248	4	31	0.016
25.5	138	2	73	0.014	229	10	32	0.044
26.5	105	5	60	0.048	217	6	35	0.028
27.5	66	0	42	0.000	149	8	24	0.054
28.5	52	2	16	0.038	101	1	23	0.010
29.5	54	0	20	0.000	108	2	19	0.019
30.5	29	2	13	0.069	119	3	21	0.025
31.5	17	0	7	0.000	112	4	15	0.036
32.5					123	4	14	0.033
33.5					145	1	4	0.007
34.5					177	2	8	0.011
35.5					194	4	14	0.021
36.5					159	0	12	0.000
37.5					119	3	12	0.025
38.5					89	1	6	0.011
39.5					63	3	1	0.048

Table 5b. Summary data for 2014 for modified Chen and Lloyd method.

	Males				Females			
Length Centre (inches	Tagged/ Clipped	Recap	Unclipped	Recap prob	Tagged/ Clipped	Recap	Unclipped	Recap prob
18.5	129	1	53	0.008				
19.5	137	3	75	0.022				
20.5	175	2	85	0.011				
21.5	199	5	116	0.025	65	1	35	0.015
22.5	237	2	69	0.008	88	1	39	0.011
23.5	230	7	80	0.030	121	2	32	0.017
24.5	214	6	70	0.028	156	3	40	0.019
25.5	150	9	48	0.060	161	5	29	0.031
26.5	94	5	42	0.053	141	5	44	0.035
27.5	46	3	26	0.065	127	4	35	0.031
28.5	36	1	17	0.028	102	4	41	0.039
29.5	31	1	17	0.032	61	3	18	0.049
30.5	17	3	6	0.176	49	2	12	0.041
31.5	4	0	11	0.000	45	2	13	0.044
32.5					39	0	12	0.000
33.5					57	0	11	0.000
34.5					77	3	15	0.039
35.5					89	2	18	0.022
36.5					105	1	15	0.010
37.5					86	0	13	0.000
38.5					63	2	10	0.032
39.5					45	0	11	0.000

Table 6. Geographical stratification in 2014 to investigate if there is evidence of a difference in recapture rates, depending on where tagged.						
	Females			Males		
Geographical Stratum	E	W	Total	E	W	Total
Tagged	1055	790	1845	1078	621	1699
Recaptured[#]	21	19	40	27	17	39
Gross recapture probability[#]	.020	.024		.025	.027	
Pearson test	$X^2 = 0.19$, p-value = .67.			$X^2 = 0.02$, p-value = .90.		
Mean days at large	35.1	41.3		35.3	41.3	
SD days at large	9.9	6.7		8.9	8.2	
ANOVA	F = 5.14, p=0.03			F = 4.99, p = 0.03		

Table 7. Summary statistics to investigate the potential bias from ignoring an E/W geographical stratification in 2014. Both sexes are also pooled so biases from heterogeneity in catchability between sexes is also present. No standard error presented because of the clear problems with the estimates – the question of interest is the degree of potential bias.

	Tagged	E	W
E	2148	43	8
W	1415	11	27
Gillnet recoveries		646	281

Pooled Petersen estimate $\hat{N}_{pp} = 41$ thousand fish.

Stratified Petersen (Darroch) $\hat{N}_{Darroch} = 41$ thousand fish.

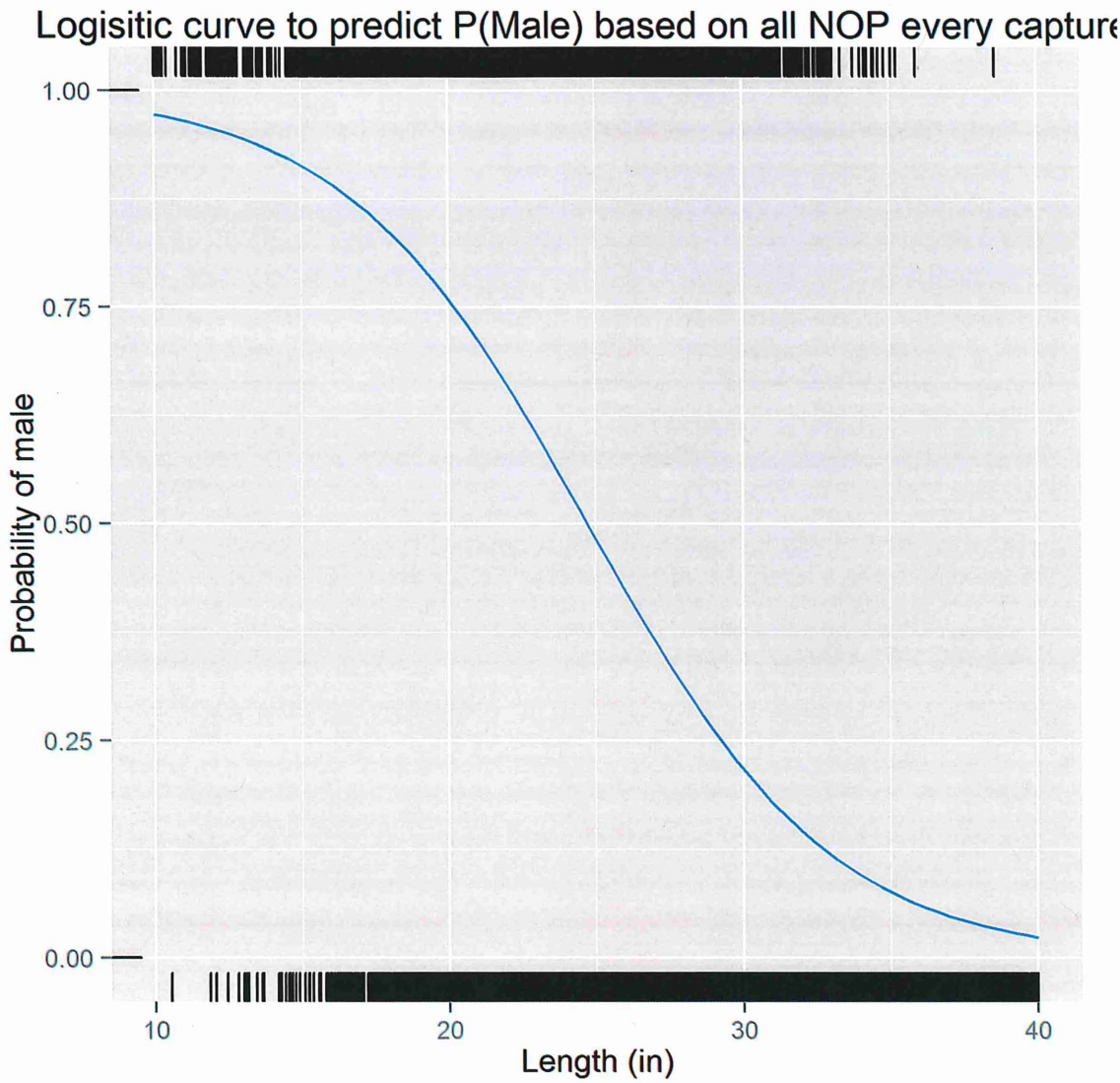

Figure 1. Logistic regression used to impute sex when not recorded as a function of length. The final fitted equation is logit(male) = 6.01 - 0.24(length).

Figure 2a. Summary of distribution of lengths in the various samples in 2013.

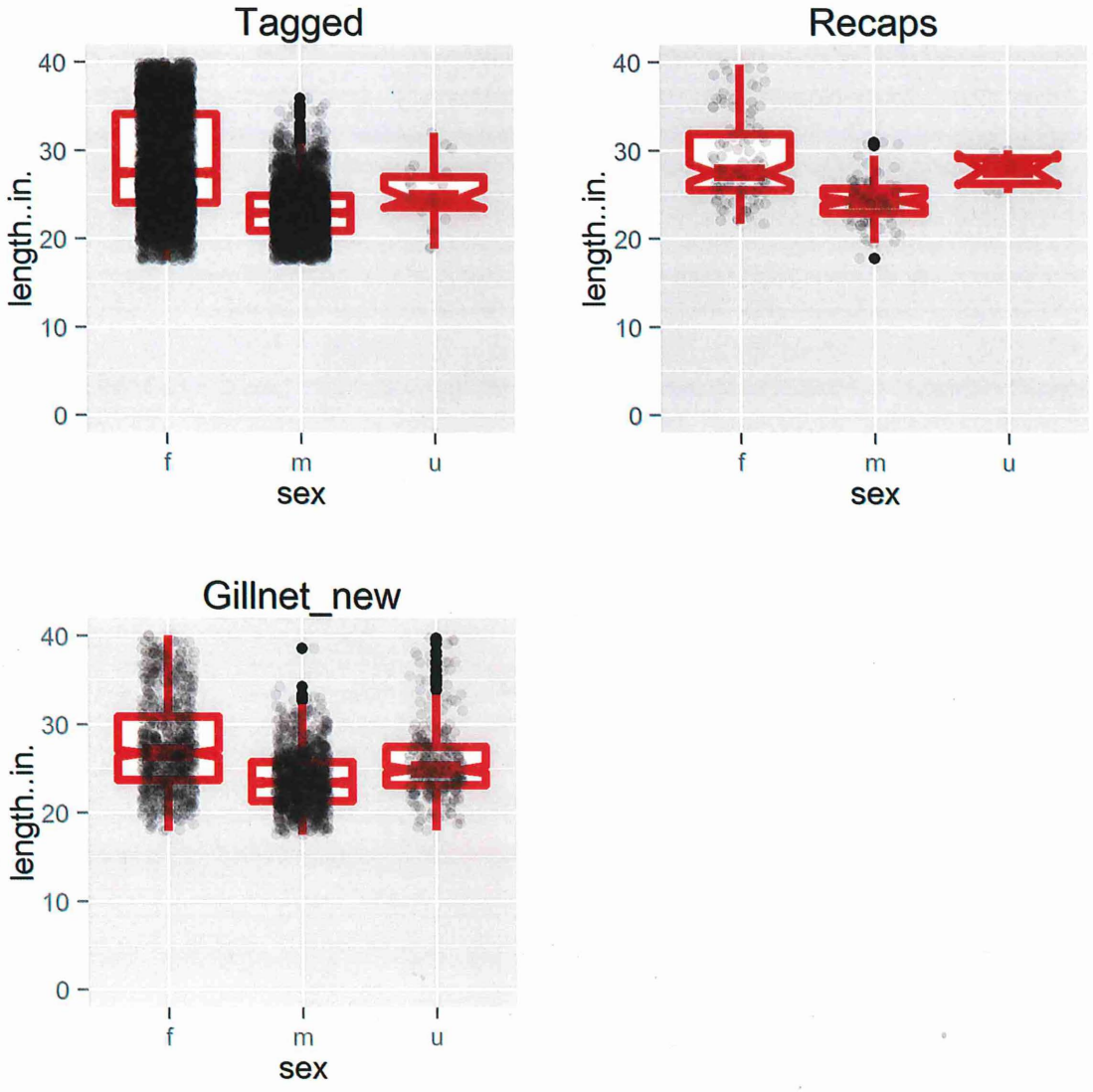

Figure 2b. Summary of distribution of lengths in the various samples in 2014.

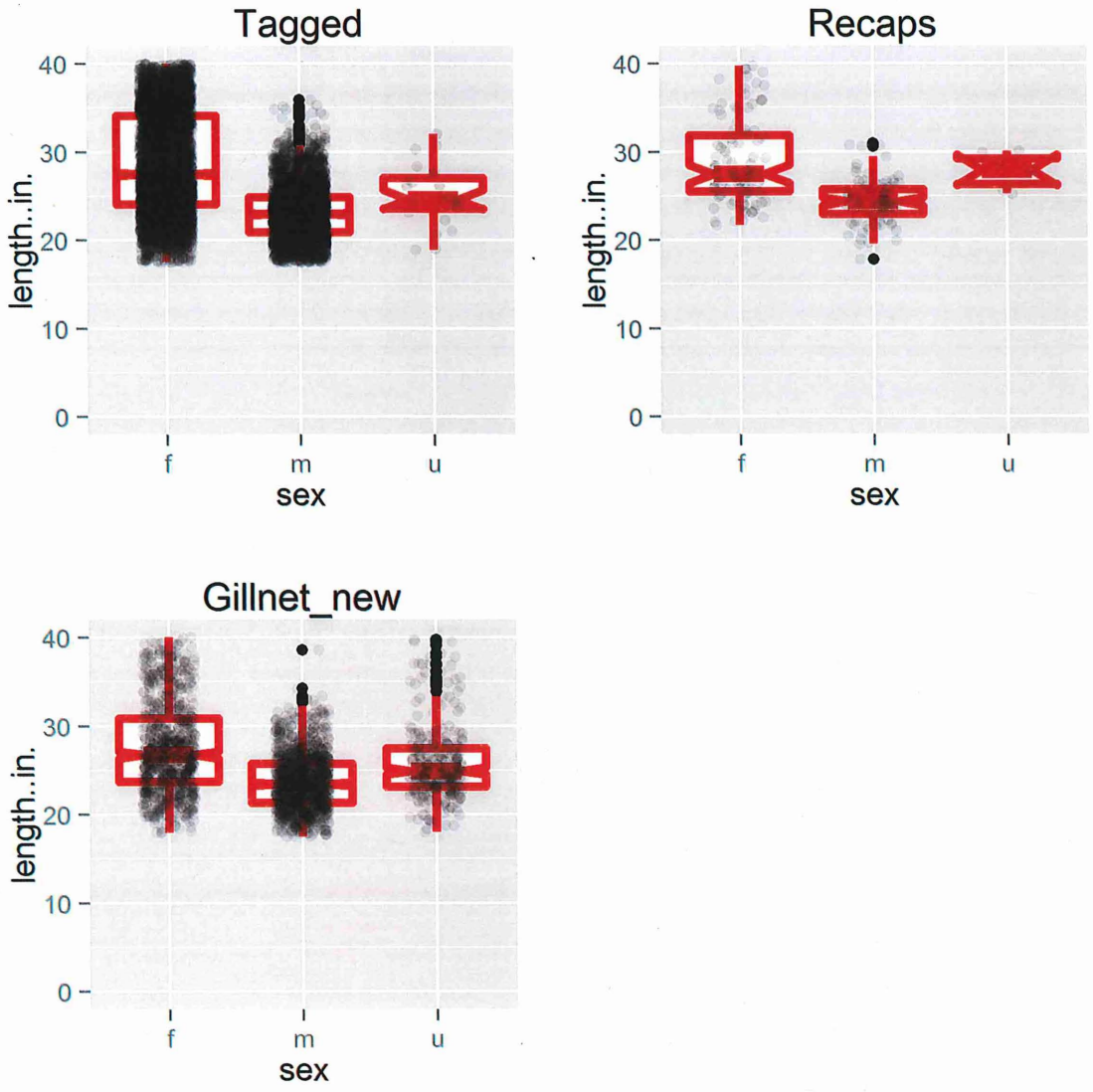

Figure 3a. Estimated abundance in 2013 from the modified Chen and Lloyd method. Points are the separate estimates computed using statistics from each length interval (Table 5a). The curve is the smoothed estimates. Total abundance estimates at top of figure are derived from smoothed estimates. Standard errors are underestimates of actual variability because the expected number of each sex allocated from the gillnet sample based on the logistic regression of Figure 2 was used.

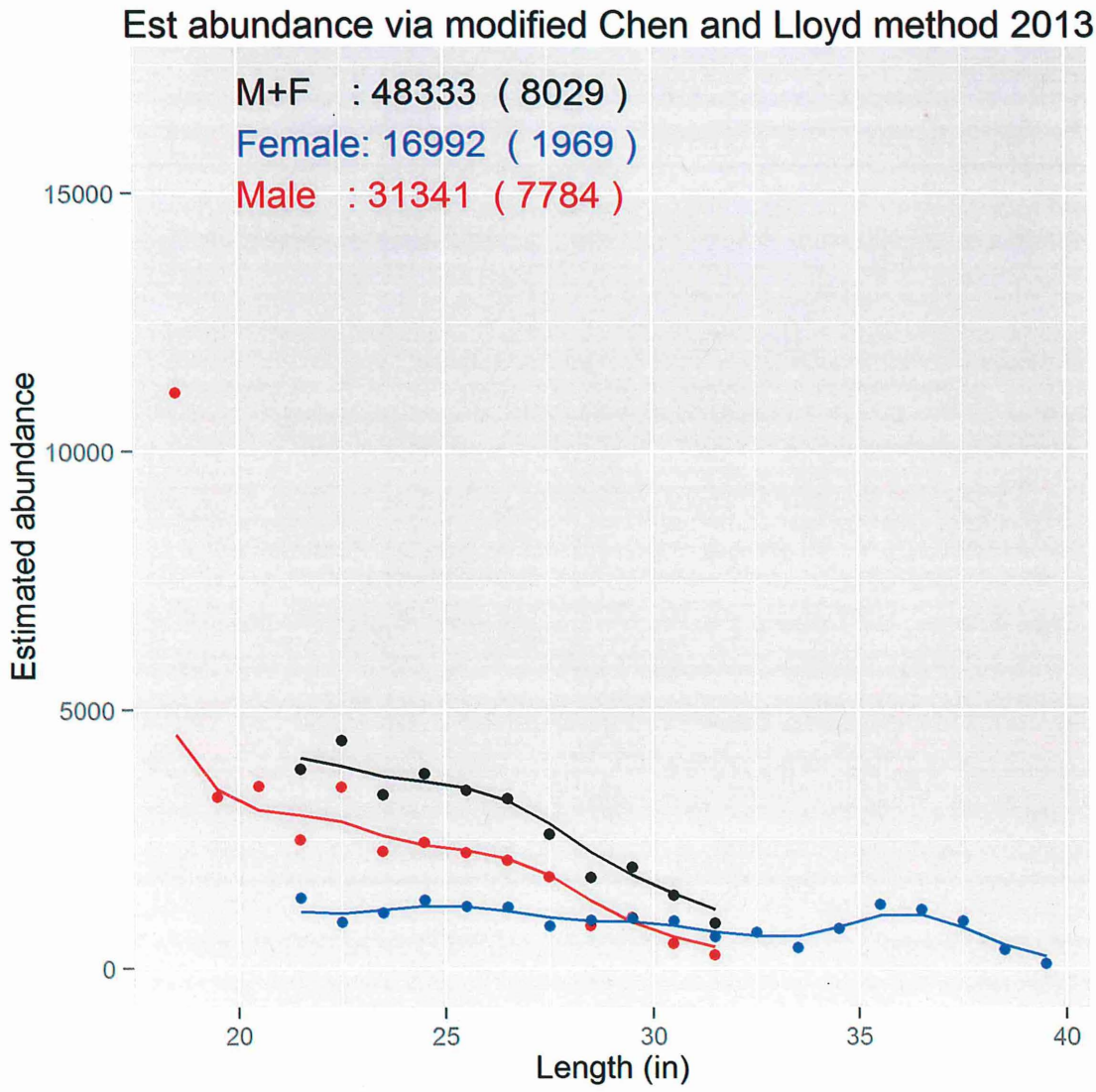

Figure 3b. Estimated abundance in 2014 from the modified Chen and Lloyd method. Points are the separate estimates computed using statistics from each length interval (Table 5b). The curve is the smoothed estimates. Total abundance estimates at top of figure are derived from smoothed estimates.

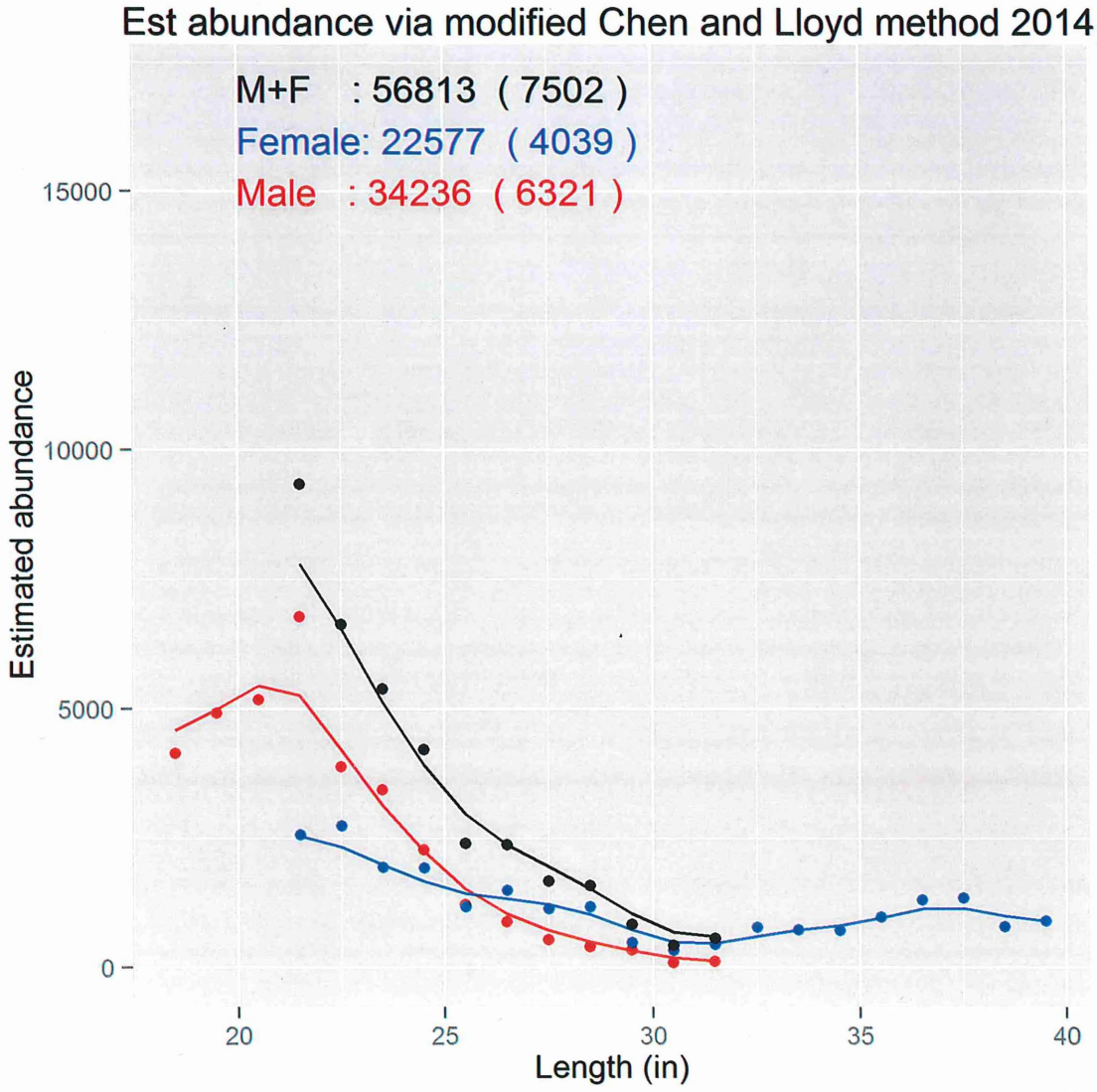

Figure 4a. Estimated gear selectivity for each sex in both samples in 2013 based on the modified Chen and Lloyd (2000) method.

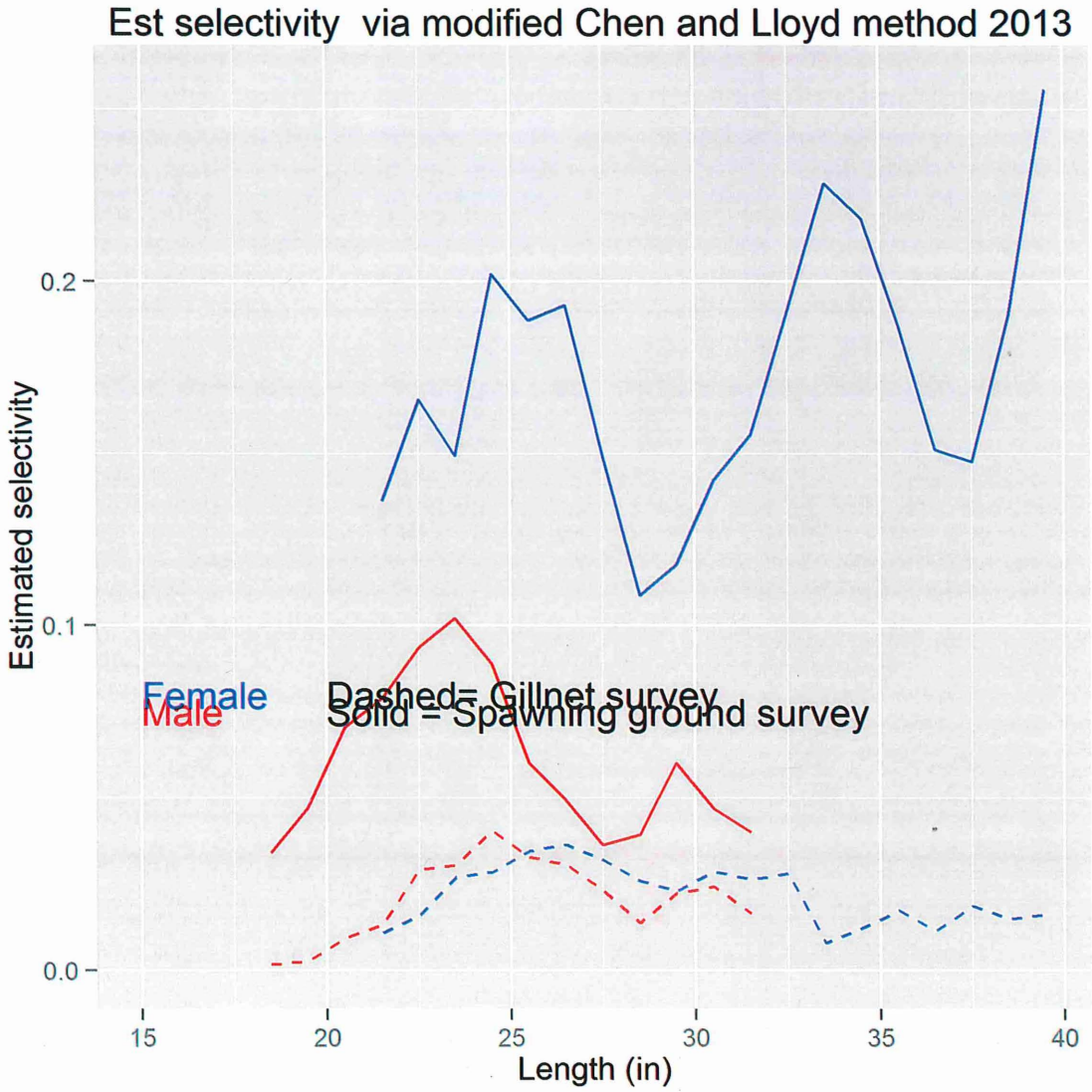

Figure 4b. Estimated gear selectivity for each sex in both samples in 2014 based on the modified Chen and Lloyd (2000) method.

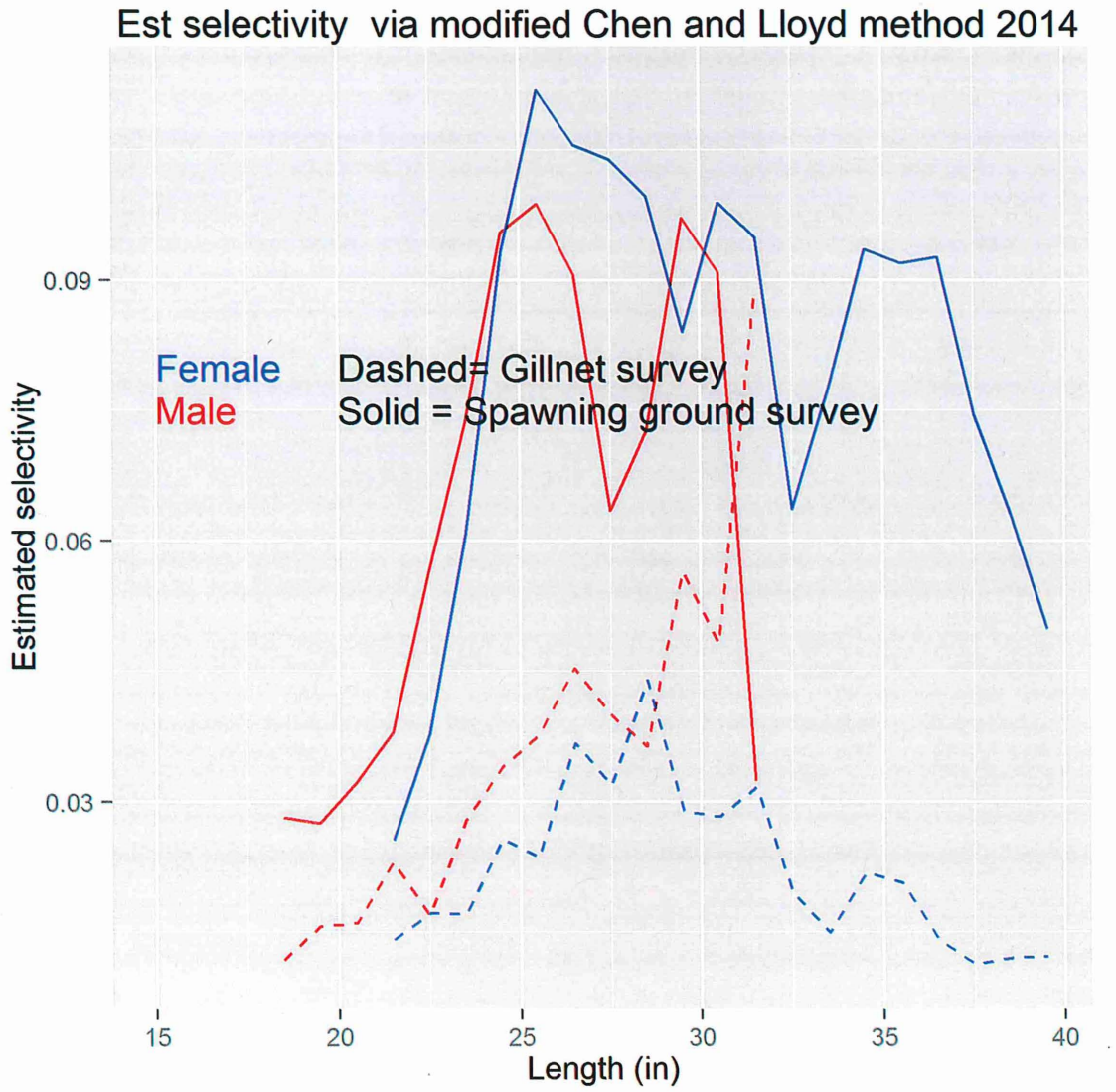

Figure 5. Illustration of the geographic separation of spawning and gillnet sampling events and movement of recaptures from spawning tagging locations to gillnet sampling locations in 2014. Plotting positions are based on median UTM values in Zone and Angling.Zone fields and jittered to prevent overplotting.

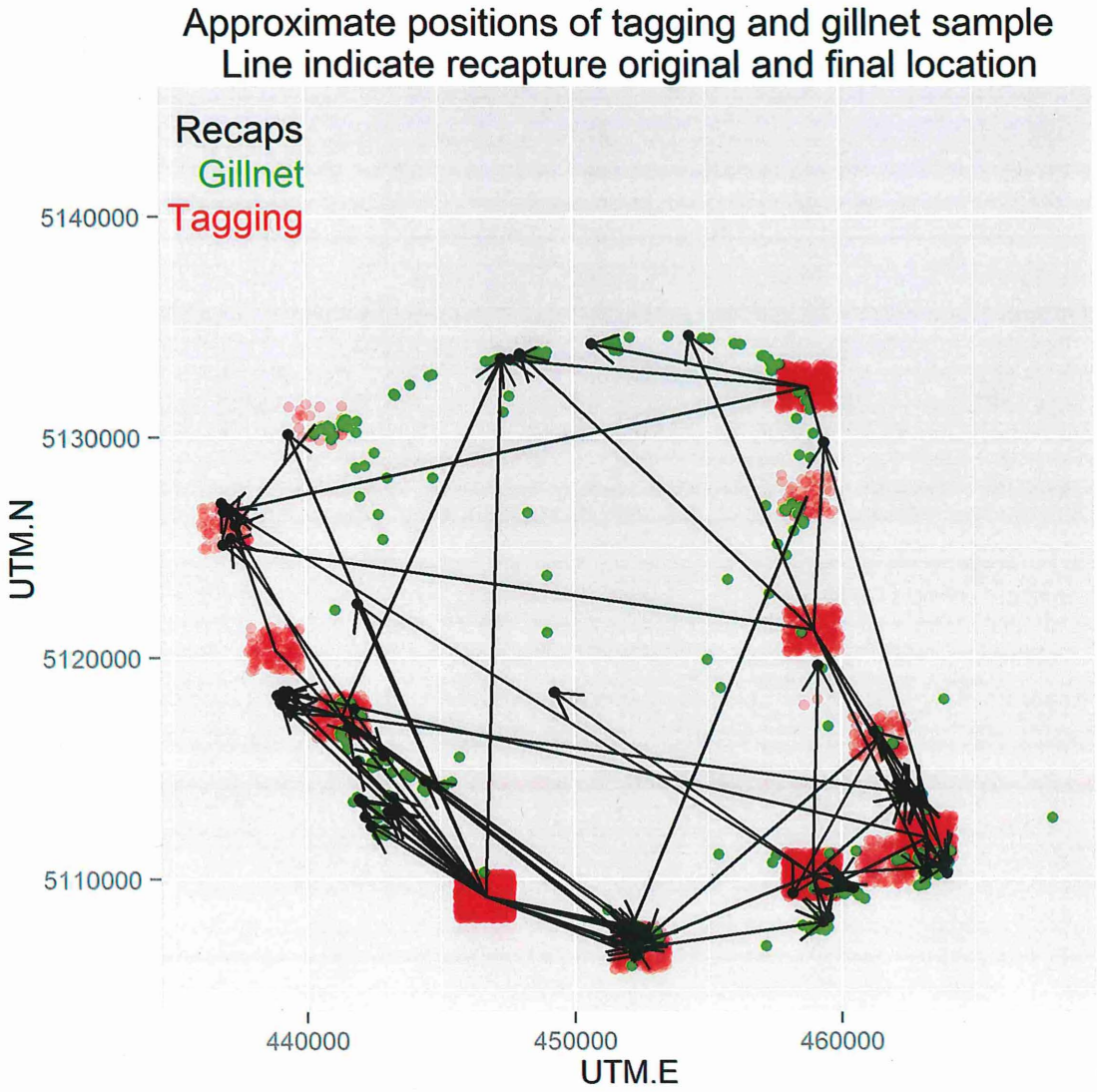

Figure 8. Comparison of estimates of total abundance from the different methods